Briquette Making Using Waste Biomass and Analysis of Its Properties

Anjali Narzary, Raghvendra Chauhan and Amarendra Kumar Das

Abstract Dry leaves, grass, agricultural waste such as straw, rice husk, plant stalks are the types of biomass that are widely available in the rural areas. They have low bulk density and cannot give controlled flame while burning, so they cannot be used as fuel. This loose biomass gives handling problems while transporting them elsewhere and this biomass, if not composted properly, is nothing but a waste. Therefore, they are mostly burnt in the open fields creating unnecessary pollution. Briquetting can be seen as a viable method to solve this issue as it is a simple and cost-effective technology. This paper presents a technique of preparing a raw biomass into a usable biomass briquette fuel. Briquettes were made from Eleusine indica grass and sawdust bonded with gelatinized taro tubers. Briquette samples were prepared using low-power screw press machine. The first sample consisted of 3:1 grass and sawdust ratio; the second sample consisted of 1:1 grass and sawdust ratio. In both the samples, 40% of taro (Colocasia esculenta) tuber in weight basis was gelatinized and added. Both the prepared samples were tested for their physical and thermal properties. The result showed that the test sample 1 showed a higher calorific value of 15.539 MJ/Kg compared to sample 2 having a calorific value of 14.683 MJ/Kg. The bulk density was found to be 0.234gm/cm^3 and 0.233gm/cm^3 for sample 1 and 2, respectively.

Keywords Briquette · Colocasia esculenta (Taro) · Thermal properties · Physical properties

A. Narzary (✉) · R. Chauhan
Centre for Rural Technology, IIT-Guwahati, Assam 781039, India
e-mail: anjalinarzary@iitg.ac.in

A. K. Das
Department of Design, IIT-Guwahati, Assam 781039, India

A. S. Kalamdhad (ed.), *Recent Developments in Waste Management*,
Lecture Notes in Civil Engineering 57,
https://doi.org/10.1007/978-981-15-0990-2_4

1 Introduction

Over 12 crore household in India does not have access to clean fuel [1]. Almost two-thirds of the Indian population still depends on firewood, cow dung cakes and other freely available biomass for cooking purposes. About one million deaths are reported annually in India due to household air pollution. According to reports, 67% of the rural household still depends on firewood and woodchips for cooking [2]. The dependence on firewood also leads to deforestation and release of CO_2 and other harmful gases to the environment. Direct combustion of loose biomass such as dry leaves, grass, straw, plant stalks is not a viable way to utilize them, as they have low density, low calorific value and they produce unwanted smoke when burnt directly [3]. Also, direct burning of biomass produces low heat and cannot give controlled flame. The use of agricultural waste, grass, leaves and other biomass with the help of appropriate technology can solve the problem of fuel requirement in rural areas. Rural areas are abounding with such wastes but most of them are wasted due to lack of good technology. Many researchers have reported various techniques and methods for energy generation from agricultural waste [4–9]. Among the many reported techniques such as gasification, biogas production, hydrogen production, pyrolysis, torrefaction, biomass briquetting is one of the most important techniques that have a promising future to solve the problem of cooking fuel in rural areas. The briquetting process is used to give higher density to the loose biomass, higher calorific value, better handling, transportation and storage properties [3]. While briquetting due to high pressure applied, the particles come close together. The natural binding agents within the feedstock are forced out of the cell making a solid bridge between the particles [10]. Some of the reported densification processes are baling, pelleting, extrusion and briquetting. Briquetting and pelleting are the most common type of densification process, which is carried out using screw press, piston press and roller press [11–18]. A very high-quality briquette can be produced using high-power-operated screw press machine [12, 19], but this technology is not feasible in rural areas where the supply of electricity is irregular. Piston press, on the other hand, can be manually operated but it has low productivity. Low-power screw press machine also exits but due to lack of high pressure and temperature, a binding agent is required [20]. Starch is the most common binder that is used as reported in many papers; other than that cassava starch, cow dung, wheat flour, coffee husk, gum Arabic, paper pulp, municipal waste, waste from paper industries have been used as a binder [3, 21–24]. A binder should be easily available, not difficult to isolate from the plant matter, should not be from the human food chain and should have good adhesive properties and also an addition of such binding agent should not degrade the thermal properties of the briquettes made.

Colocasia esculenta (Taro) is a perennial tropical plant grown widely for consumption purpose. Assam is one of the major taro producing states of India, and these plants grow widely in the swamps and is widely available in the villages [25]. The tuber is reported to have 70–80% starch content [26, 27]. The tender leaf, stem and tuber are edible, but the tuber of wild taro plant is not edible. Therefore, they do not have any use. These tubers were used as a binder for briquette in the present research. Taro is easily available in the villages and due to its high starch content, it has a potential of being used as a binder for briquetting which is being tested in this research.

The objectives of the present research described in this paper can be listed as follows:

- To evaluate the performance of Taro tuber as a binder for briquetting using a low power screw press briquetting machine.
- To prepare samples by varying the ratio of sawdust and Eleusine indica grass by keeping the tuber percentage constant at 40% by weight.
- To analyze the physical and thermal properties of the briquettes obtained.

Preparation of the briquettes

The grass was dried in the sun for 6 h and then converted to a smaller size (Fig. 1) manually using cleaver knife as the large material particles when pressed in the screw press machine without cutting choked the machine. The grounded particle was then mixed in a particular ratio with sawdust obtained from a nearby small firewood shop in line with the work of Birwatkal et al. [10]. After mixing with the binder and water, mixture was ready to be put in the screw press machine.

Preparation of the Binder

The taro tubers were collected manually in the college campus itself (Fig. 2). The tubers were cut out from the plant and then washed to clear off all the stuck soil. It was then stored for use for a week.

For preparation of the binder, the taro was first peeled and weighed (weight by weight basis) for 40% ratio with the biomass. It was then cut into smaller pieces and

Fig. 1 Sun dried and grounded grass

Fig. 2 Taro tubers collected manually in the college campus

grounded using a mixer grinder by adding 100 ml of water. The paste obtained is then added with measured volume of water to obtain 50% water content in the total mixture of the feed for the machine. The mixture is then boiled to gelatinize it to bring out its pasting property (Fig. 3) as described in the paper [28]. Even though the taro tuber is rich in starch content, still the extraction of starch from the tuber is very difficult as the starch takes long time to settle down unlike other starches, which result in microbial contamination and effects the quality of the starch [29]. Therefore, we have tried to directly use the tuber as a binder for the briquettes that were prepared in this research. Wild taro also consists of higher amount of oxalic acid, which causes itching [30] so the work had to be carried out wearing gloves and taking precautions, so that it does not come into contact with the body.

Fig. 3 Gelatinized mixture

Analysis of the briquettes

The briquettes (sample1 and sample 2) (Figs. 4 and 5) were oven-dried at 100 °C for 3 h and stored for analysis that was to be performed. Sun drying was not possible due to the rainy season and while drying inside the room, the briquettes remained damp even after 3 days of drying. Therefore, analysis of the briquettes was performed on the oven-dried samples according to the methods given by Birwatkar et al. [10].

The physical properties of the briquettes determined were moisture content, bulk density, shatter resistance, degree of densification. The thermal properties determined were calorific value, volatile matter content, ash content and fixed carbon content.

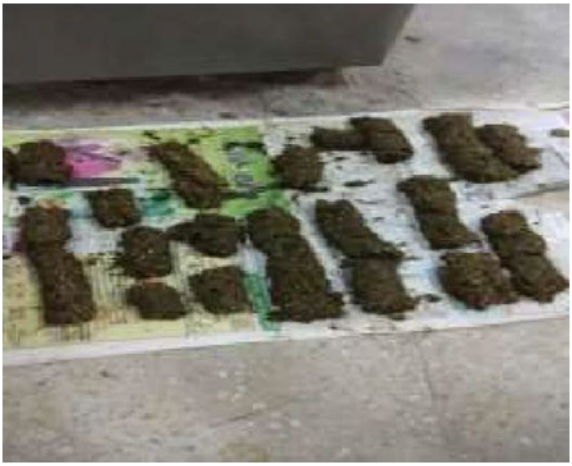

Fig. 4 Oven-dried briquettes of sample 1

Fig. 5 Oven-dried briquettes of sample 2

Moisture Content

Oven-drying method is used to find out the total moisture present on the sample. The sample was placed in the oven at 105 °C for 16 h. The loss in weight was calculated by using the following formula:

$$\text{M.C. (\% wb)} = \frac{W2 - W3}{W2 - W1} \times 100$$

Here, $W1$ denotes the weight of the empty crucible, $W2$ denotes weight of crucible with the sample and $W3$ denotes $W2$ after drying, all units in gram.

Bulk density

The bulk density of material was found out by using by weighing the mass of the sample and measuring its volume and then using the formulae:

$$\text{Bulk density}\left(\frac{\text{Kg}}{\text{m}^3}\right) = \frac{\text{mass of the sample (kg)}}{\text{volume of the sample }(\text{m}^3)}$$

Shatter resistance test

This test was performed to see the strength of the briquettes against external forces. A piece of briquette would be dropped three times on a hard floor from a known height and the previous and later weight minus the initial weight would give the shatter resistance of the sample:

$$\text{Percent weight loss} = \frac{W1 - W2}{W1}$$

% shatter resistance = 100 – % weight loss

Here, $W1$ is the weight of briquette before shattering and $W2$ is the weight of briquette after shattering in grams.

Degree of Densification

Degree of densification shows us numerically, how much we could compact using our method of densification. We have to measure the density of the biomass before briquetting and after briquetting and put in the given formulae to find the degree of densification:

$$\text{Degree of densification} = \frac{\text{Density of briquette} - \text{Density of rawmaterial}}{\text{Density of the raw material}}$$

Energy Density Ratio

This particular ratio shows us how much of energy one unit volume of the briquetted sample can contain or produce when burned. This could simply be found using the following formulae:

$$\text{Energy density ratio} = \frac{\text{Energy content of briquetted fuel}\left(\frac{\text{Kcal}}{\text{m}^3}\right)}{\text{Energy content of raw biomass}\left(\frac{\text{Kcal}}{\text{m}^3}\right)}$$

Thermal properties analysis of the briquette samples

The most important among the thermal analysis test of briquettes are the calorific value, ash content, volatile matter and fixed carbon.

Calorific Value, kcal/kg

The calorific value of the sample can be found using an instrument called a bomb calorimeter. Where a small amount of sample is burnt with 25 atmospheric pressure of oxygen. Once the combustion starts, the change in the temperature is noted until a peak value is obtained and the reading gradually decreases. The following formulae is used to determine the calorific value:

$$\text{Calorific value}\left(\frac{\text{Kcal}}{\text{kg}}\right) = \frac{(W + W) \times (T2 - T1)}{X}$$

where

W is the mass of water used in the calorimeter (2000 g),

w is the water equivalent of the apparatus (455 g),

$T1$ = Initial temperature of the water inside the calorimeter (°C),

$T2$ = Final temperature of the water in the calorimeter (°C), X = Mass of fuel sample taken in the crucible (g).

Volatile Matter

The sample after drying is weighed and placed in a crucible with a lid. The covered crucible was then placed in a muffle furnace whose temperature is set to 950 ± 20 for 7 min. Once the sample cools down, the weight is measured and the difference of the weight was reported as volatile matter on percentage basis

$$\text{Volatile Matter }(\%) = \frac{W3 - W4}{W2 - W1}$$

where

$W1$ denotes weight of the crucible, $W2$ denotes weight of crucible with the sample taken,

$W3$ denotes weight of crucible with sample after moisture removal and $W4$ denotes weight of crucible with the sample after heating in a muffle furnace, all units in grams.

Ash Content

For this analysis, the sample is placed in a closed crucible which was then heated in a muffle furnace at 700 ± 50 °C for one and a half hours. After cooling the sample in a desiccator, the sample is weighed for every half an hour for the weight loss until a constant weight is obtained. Weight of ash divided by the initial weight of the sample is the ash content of the sample:

$$\text{A.C.}\,(\%) = \frac{W3 - W1}{W2 - W1} \times 100$$

where
$W1$ = weight of the empty crucible, g
$W2$ = weight of crucible + sample taken from the second stage
$W3$ = weight of crucible + ash left in crucible, g.

Fixed Carbon
The mass balance formula was used for the calculation given below.

$$\text{Fixed Carbon }(\%\ ) = 100 - \ \%\ \text{of}(MC + VM + AC)$$

where
FC = Fixed carbon, MC = Moisture content, VM = Volatile matter and AC = Ash content, all in percentage value.

Techno-economic Analysis
For making the briquettes reported in this paper, we require a low-power screw press briquetting machine of rating 0.7 Kwatt to continuously produce the briquettes. A heating vessel could be used to gelatinize the taro tuber. Cutting and cleaning of the tubers can be done using any cutting tools like knife as they are soft, but gloves are required for the job as the oxalic acid content may cause itching in the body part that came into contact with the tuber. The raw material used for the study was grass, which is being cut and disposed as waste in the campus and the sawdust was procured from a nearby shop. The cleaver's knife used in the study was also obtained from a nearby blacksmith shop. So, the capital cost of the machine can be a sum of the briquetting machine which cost INR 8000, the cost of locally made cleaver's knife is INR 300, any heating vessel cost is around INR 150. So, the capital cost amounts to INR 8450.

For the operational cost, the grass was brought from the field to the working site in a cart manually pulled by a labour. The labour cost charged for it was INR 100 per cart, which was used throughout the study to make almost 3–4 kg of briquettes. The cost of the sawdust was INR 90 for one bag (1.5 m × .5 m) dimension. INR 100 for bringing it to the destination. The time required for preparation of the grass is 2 h and taro preparation takes just 20 min and preparing the mixture and putting in the briquetting machine to get the output will take another 1 h. Therefore, the total labour cost will be according to labour wage chart by Wikipedia, i.e. 70 INR per hour, equals to 280 INR (approx.) per labour [31]. Electricity cost for 0.7 unit equals 65 INR (approx.) including fixed charge, metre rent and energy charge [32]. Therefore, the total operational cost to produce 3–4 kg of briquettes two labourers costing 560 INR plus 200 INR transportation and 45 INR(for half bag) raw material accounting to an amount of 870 INR.

2 Results and Discussion

The briquettes (samples 1 and 2) (Figs. 4 and 5) obtained from the machine used were cylindrical. The average length of the briquettes measure during the analysis period was found to vary from 4 cm to 9 cm and radius is 1.25 cm.

Physical properties

Sl no.	Sample	Composition	Bulk density (g/cm^3)	Shatter resistance (%)	Degree of densification
1	1	Grass: Sawdust::75:25	0.234	73.52	0.054
2	2	Grass: Sawdust::50:50	0.233	83.55	0.078

Thermal properties

Sl no.	Sample	Composition	Moisture	Ash	Calorific	Volatile	Fixed	
		Grass:SawDust	Content	Content	Value	Mater	Carbon (%)	
			(%)	(%)	(MJ/kg)	(%)	Dry	Wet
1	1	75:25	0.38	4.08	15.539	86.71	9.20	8.83
2	2	50:50	0.54	4.618	14.683	88.93	6.45	5.91

3 Conclusion

Two briquette samples were successfully prepared using grass and sawdust in different proportions and analysed. The following conclusions were made

Taro tuber could not bind at a proportion less than 40% by weight of the biomass taken. 100% grass sample could not be prepared in the machine used in the study. The process of chopping the grass to a smaller size using cleaver knife was very time consuming and less efficient, so in future, a grass chopping machine could be designed in order to optimize the time required to process higher amount of biomass. Oven-drying gives good result but this facility cannot be availed by the rural people, so the test can be performed by sun drying in the future work. The compaction density was low when compared to other works reported in the literatures cited. Sample 2 showed better physical characteristics and sample 1 had better thermal properties.

References

1. http://niti.gov.in/content/electricity-and-clean-cooking-strategy-india. Accessed 16 Oct 2017
2. https://scroll.in/article/747551/67-of-indias-rural-households-still-use-firewood. Accessed 16 Oct 2017
3. Quereshi, S., Ahmad, E., Pant, K.K., Dutta, S.: Recent advances in production of biofuel and commodity chemicals from algal biomass. In: Algal Biofuels, pp. 393–419. Springer International Publishing, Cham (2017)
4. Chandra, R., Takeuchi, H., Hasegawa, T.: Methane production from lignocellulosic agricultural crop wastes: a review in context to second generation of biofuel production. Renew. Sustain. Energy Rev. **16**(3), 1462–1476 (2012)
5. Guo, X.M., Trably, E., Latrille, E., Carrere, H., Steyer, J.P.: Hydrogen production from agricultural waste by dark fermentation: a review. Int. J. Hydrogen Energy **35**(19), 10660–10673 (2010)
6. Sarkar, N., Ghosh, S.K., Bannerjee, S., Aikat, K.: Bioethanol production from agricultural wastes: an overview. Renew Energy **37**(1), 19–27 (2012)
7. Hobson, P.N.: Biogas production-agricultural wastes. Rep, Watt Comm Energy **5**, 37–44 (1979)
8. Sansaniwal, S.K., Pal, K., Rosen, M.A., Tyagi, S.K.: Recent advances in the development of biomass gasification technology: a comprehensive review. Renew. Sustain. Energy Rev. **72**, 363–384 (2017)
9. Bhattacharya, S.C., Sett, S., Shrestha, R.M.: State of the art for biomass densification. Energy Sources **11**(3), 161–182 (1989)
10. Birwatkar, V.R., Khandetod, Y.P., Mohod, A.G., Dhande, K.G., Source, O.E., Dapoli, T.: Physical and thermal properties of biomass briquetted fuel. Ind. J. Sci. Res. Tech **2**(4), 55–62 (2014)
11. Kaliyan, N., Morey, R.V., White, M.D., Doering, A.: Roll press briquetting and pelleting of corn stover and switchgrass. Transactions of the ASABE **52**(2), 543–555 (2009)
12. Florentino-Madiedo, L., Díaz-Faes, E., Barriocanal, C., Castro-Díaz, M., Snape, C.E.: Importance of biomass and binder selection for coking briquette preparation. Their effect on coal thermoplastic properties. Energy & Fuels **32**(10), 10727–10736 (2018)
13. Muazu, R.I., Stegemann, J.A.: Biosolids and microalgae as alternative binders for biomass fuel briquetting. Fuel **194**, 339–347 (2017)
14. Wu, S., Zhang, S., Wang, C., Mu, C., Huang, X.: High-strength charcoal briquette preparation from hydrothermal pretreated biomass wastes. Fuel Process. Technol. **171**, 293–300 (2018)
15. Rahaman, S.A., Salam, P.A.: Characterization of cold densified rice straw briquettes and the potential use of sawdust as binder. Fuel Process. Technol. **158**, 9–19 (2017)
16. Emadi, B., Iroba, K.L., Tabil, L.G.: Effect of polymer plastic binder on mechanical, storage and combustion characteristics of torrefied and pelletized herbaceous biomass. Appl. Energy **198**, 312–319 (2017)
17. Xue, Z., Liu, Q., Emmanuel, P., Qin, J., Liu, D., Gao, W., Bai, X.: Analysis on the effects of pre-heating temperature on mechanical properties of pellets made from corn stalk powder. Int. J. Heat Technol. **35**(2), 421–425 (2017)
18. Shahapur, A., Desai, N.M., Kader, M.A.: Biomass briquette as an alternate source of energy-an economic feasibility analysis. J. S. Pac. Agric. **20**, 25–33 (2018)
19. Tumuluru, J.S., Wright, C.T., Kenney, K.L., Hess, R.J.: A technical review on biomass processing: densification, preprocessing, modeling and optimization. In: 2010 ASABE Annual International Meeting, June 2010
20. Bhatkar, O.P., Patil, S.S., Tambe, S.P., Wafelkar, N.N., Manjarekar, P.P.: Design and fabrication of densified biomass briquette maker machine. Int. J. Environ. Agric. Biotechnol. **2**(2), 0805–0807

21. Karunanithy, C., Wang, Y., Muthukumarappan, K., Pugalendhi, S.: Physiochemical characterization of briquettes made from different feedstocks. Biotechnol. Res. Int. **2012**, 12 (2012)
22. Beker, Ü.G.: Briquetting of Afşin-Elbistan lignite of Turkey using different waste materials. Fuel Process. Technol. **51**(1–2), 137–144 (1997)
23. Sotannde, O.A., Oluyege, A.O., Abah, G.B.: Physical and combustion properties of briquettes from sawdust of Azadirachta indica. J. For. Res. **21**(1), 63–67 (2010)
24. Kishan, B.S., Kumar, K., Santhosh, T.J., Gangadhar, A.D.: Design and fabrication of low cost briquetting machine and estimation of calorific values of biomass briquettes. Int. J. Innov. Res. Sci. **5**(7), 12454–12461 (2016)
25. Zhanbin, C.: Normal temperature briquetting technology for biomass with original moisture content. In: International Conference on Bioenergy Utilisation and Environmental Protection, 6th LAMNET Workshop-Dalian, China, pp. 1–6
26. http://www.agrifarming.in/taro-root-farming/. Accessed 17 Oct 2017
27. Jane, J., Shen, L., Chen, J., Lim, S., Kasemsuwan, T., Nip, W.: Physical and chemical studies of taro starches and flours1 2. Cereal Chem. **69**(5), 528–535 (1992)
28. Agama-Acevedo, E., Garcia-Suarez, F.J., Gutierrez-Meraz, F., Sanchez- Rivera, M.M., San Martin, E., Bello- Pérez, L.A.: Isolation and partial characterization of Mexican taro (Colocasia esculenta L.) starch. Starch-Stärke **63**(3), 139–146 (2011)
29. Lu, T.J., Lin, J.H., Chen, J.C., Chang, Y.H.: Characteristics of taro (Colocasia esculenta) starches planted in different seasons and their relations to the molecular structure of starch. J. Agric. Food Chem. **56**(6), 2208–2215 (2008)
30. Moorthy, S.N.: Extraction of starches from tuber crops using ammonia. Carbohyd. Polym. **16** (4), 391–398 (1991)
31. https://en.wikipedia.org/wiki/List_of_minimum_wages_by_country. Accessed 1 Dec 2018
32. https://www.bijlibachao.com/electricity-bill/online-electricity-bill-calculator-for-all-states-in-india.html. Accessed 1 Dec 2018